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Research Article

Correlation Between Cyanobacterial Population and Water Quality Parameters in Geum River Region

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Abstract

The occurrence of natural disasters have recently increased due to global warming, and water quality improvement projects are carried out in rivers for various purposes including restoring polluted water environment and aquatic ecosystem, and managing water resources. The most serious problem occurring in streams is algal bloom, or an increase in the population of blue-green algae, in terms of water quality. A correlation analysis was conducted on water quality parameters for the Sejong Weir, Gongju Weir, and Baekje Weir located in the Geum River, which is recently experiencing improvement in water quality by opening weirs. In particular, the correlation between the number of cyanobacterial cells and major water quality parameters of streams was analyzed based on the Pearson's correlation analysis. Furthermore, a multiple regression equation was derived by setting the number of cyanobacterial cells at each weir as a dependent variable and water quality parameters, which have a high correlation, as independent variables, in order to investigate the correlation between the cyanobacterial population and the concentration of water quality parameters in major streams of the Geum River. The parameters that had a statistically significant correlation were selected based on the correlation analysis between the number of cyanobacterial cells and water quality parameters per measurement point. The multiple regression equation of the number of cyanobacterial cells proposed in this study can be used to predict the possible number of cyanobacterial cells depending on the concentration of water quality parameters, thus being utilized in water quality management of the Geum River.

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Introduction

The occurrence of natural disasters such as droughts and floods has recently increased due to global warming and extreme weather conditions. Water quality improvement projects are carried out in rivers for various purposes including restoring polluted water environment and aquatic ecosystem, developing waterfront, and managing water resources. As one of the well-known examples of these projects, the Four Major Rivers Restoration Project was carried out in 2010 in which 16 weirs were built in the Han River, Geum River, Yeongsan River, and Nakdong River.

The retention time of the water system in the Geum River increased after the construction of weirs was completed, thus causing algal blooms which especially has a negative effect on hydrophilic activities in summer due to odor and damaged aquatic scenery (Chong et al, 2015). Particularly, the occurrence of algal blooms in the Geum River and the Yeongsan River has been reported to increase every year (Ministry of Envirionment, 2016). In general, the downstream of a river has an abundant amount of nutritive salts compared to the upstream for which primary production can drastically increase depending on the situation, resulting in algal bloom (Son, 2013).

Korea has a tropical monsoon climate, thus exhibiting a great difference between the amount of precipitation concentrated in summer and the seasonal flow in rivers, which accelerates the damage caused by algae bloom (Kim et al, 2014). The majority of algal bloom occurring in rivers in Korea is harmful cyanobacteria for which Anabaena, Aphanizonmenon, Oscillatoria, and Microcystis have been designated as harmful cyanobacteria by the Ministry of Environment. Harmful cyanobacteria are destroying the aquatic ecosystem by emitting toxins. Most of the studies conducted in Korea on cyanobacteria focused on the effects of biological factors and environment on the occurrence of cyanobacteria, the toxin producing substances in cyanobacteria and the evaluation of toxicity, and control measures for cyanobacteria, but the mechanism of algal bloom still has not been identified (National Institute of Environment Research, 2014).

Considering that there is insufficient study on the water quality parameters which cause cyanobacteria in the Geum River after the Four Major Rivers Restoration Project, a comprehensive study on nutritive salts and climate in addition to water quality parameters must be conducted. Moreover, algal bloom is part of natural phenomena and occurs in a time series in diverse forms; thus, it must be examined based on the data collected over a long period of time (Lee et al, 2014).

In this study, the correlation between the number of cyanobacterial cells and major water quality parameters of rivers – precipitation amount, water temperature (WT), pH level, dissolved oxygen (DO), biological oxygen demand (BOD), chemical oxygen demand (COD), suspended solids (SS), total nitrogen (TN), total phosphorus (TP), chlorophyll-a (Chl-a), electrical conductivity (EC), nitrate nitrogen (NO3-N), ammoniacal nitrogen (NH3-N), phosphate (PO4-P), dissolved total nitrogen (DTN), dissolved total phosphorus (DTP), and total organic carbon (TOC) – was examined based on the Pearson's correlation analysis.

Furthermore, a multiple regression equation was derived by setting the number of cyanobacterial cells at each weir as a dependent variable and water quality parameters, which have a high correlation, as independent variables, in order to investigate the correlation between the cyanobacterial population and the concentration of water quality parameters in major streams of the Geum River. A multiple regression analysis, which is a widely known statistical analysis method, has been used for estimating the zero yield of water supply (Jang et al, 2019). Also, previous studies have used a multiple regression analysis to predict that water temperature and TN have the greatest effect on harmful cyanobacteria (Beaulieu et al, 2013) and to predict the concentration of Chl-a at the weir built in the Han River (Oh, 2016).

Theoretical background

Correlation analysis

A correlation analysis is conducted to identify a linear correlation between two variables, which is useful for examining whether a variable is correlated with the other variable and to what extent they are correlated (Park et al, 2017). Here, the Pearson’s correlation coefficient (r) which is a commonly used measure was adopted. The coefficient ranges from -1 to 1 in which the correlation is stronger when the absolute value of the coefficient is closer to 1 (Park et al, 2014). In other words, the correlation coefficient is a measure used to represent the linearity, which requires a careful interpretation of the result (Kwak, 2016). Moreover, a scatter plot can also be used to find the relationship between two variables. A scatter plot is a type of plot representing n number of pairs consisting of x and y coordinate values, which can indicate the correlation between two variables of various forms (Kwak, 2016).

Multiple regression analysis

A regression analysis is useful for verifying the relationship of two variables, for which a functional relationship is known, through actual circumstances or data and for predicting a variable based on the other variable (Choi et al, 2010). A regression model is derived by defining the functional relationship between an independent variable, which is an explanatory variable explaining the cause, and a dependent variable, which is a response variable indicating the result (Park et al, 2017). A linear model between a dependent variable and one independent variable is called a simple linear regression model, while a linear model between one dependent variable and two or more independent variables is called a multiple linear regression model. A multiple linear regression model is shown below.

$$Y = a_1 + b_1x_1 + b_2x_2 \cdots + b_nx_n$$

Y = Dependent variable

a = Regression equation constant

b = Linear regression coefficient

x = Independent variable value

In a multiple regression analysis, independent variables must be mutually independent, and the relationship between a dependent variable and independent variables is assumed to be linear for the coefficient.

Research details and method

Study Area

The drainage area and basin length of the Geum River are 9,912 km2 401 km, respectively, which is the third largest in South Korea after the Nakdong River and the Han River. In terms of geographical features, mountainous areas are at the boundary of the basin, and plains are formed in middle and downstreams (Kim et al, 2016).

The average annual temperature and annual precipitation of the Geum River region are 11.0 - 12.5℃ and 1,100 - 1,300 mm, respectively. The downstream region has a precipitation of 1,100 mm or less, while the upstream region has a precipitation of around 1,300 mm which is considered as a rainy area in the southern coast of Korea (Kim et al, 2016). As of 2005, the pollution load of the Geum River region had a higher portion of point pollution sources than non-point pollution sources (Son, 2016). Figure 1 shows the study area and the location of weirs built in the Geum River.

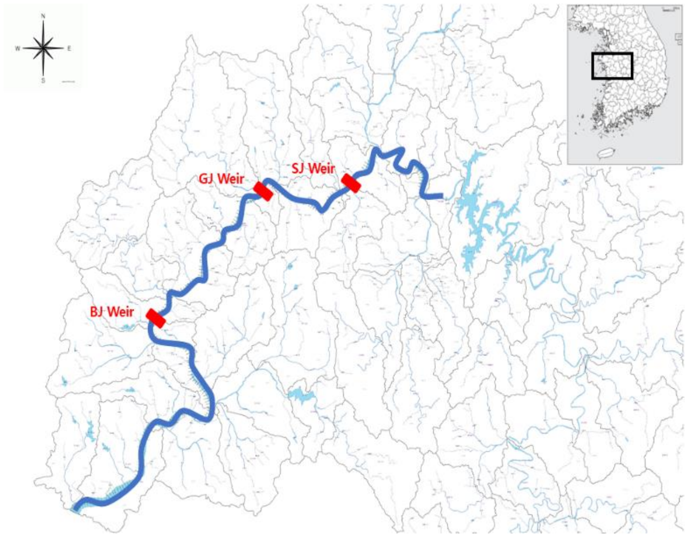

Figure 1. Study Area

Point of research and time

In this study, the data provided by the Water Environment Information System (http://water.nier.go.kr/) were used. After the construction of Sejong(SJ) Weir, Gongju(GJ) Weir, and Baekje(BJ) Weir was completed as part of the Four Major Rivers Restoration Project between January 2012 and December 2019, the corresponding annual and monthly data of the water quality prediction system during which the number of harmful cyanobacterial cells was at Attention or higher level of the algae warning system as well as the data on water quality monitoring network were used. For precipitation, the climate data of the region closest to the study area provided by the Water Resources Management Information System (http://www.wamis.go.kr/) were used. Table 1 shows the point of research that is closest to the water quality prediction system and water quality monitoring network. Table 2 presents the warning criteria for algae alarm system.

Table 1

Point of research

	Sejong Weir		Gongju Weir		Baekje Weir	
	Investigation point name	Collection Location	Investigation point name	Collection Location	Investigation point name	Collection Location
Water Quality Forecast System	YeonGI	Geum Nam Bridge	Geum Gang	500m upper stream of Gonju Weir	BuYeo	500m upper stream of Baekje Weir

Water Quality Measuring Network	YeonGI	-	Geum Gang	-	BuYeo	-

Table 2

Level of Algae alarm system in South Korea

Level	Attention	Warning	Bloom
Algae(Cells/mL)	1,000	10,000	1,000,000

Analysis of water quality characteristics

With respect to water quality parameters, WT, pH level, DO, BOD, COD, SS, TN, TP, Chl-a, EC, NO3-N, NH3-N, PO4-P, DTN, DTP, TOC, and precipitation measured once a week at the water quality monitoring network were used to deduce a multiple regression equation for the correlation analysis on the number of cyanobacterial cells of the water quality prediction system. IBM SPSS Statistics program was used for the statistical analysis on SJ, GJ, and the BJ Weirs in the Geum River region.

The Pearson's correlation analysis, which is a commonly used method, was applied to analyze the number of cyanobacterial cells and major water quality parameters. Furthermore, a multiple regression equation was derived by setting the number of cyanobacterial cells at each weir as a dependent variable and water quality parameters, which have a high correlation in the Pearson's correlation analysis, as independent variables, in order to investigate the correlation between the cyanobacterial population and the concentration of water quality parameters in major streams of the Geum River.

The results of correlation analysis and multiple regression analysis

Water quality of three weirs in the Geum River region

The average numbers of harmful cyanobacterial cells in the Geum River during the months of June through October from January 2012 to December 2019, which correspond to the Attention level (1,000 cells/mL) of the algal alarm system, are shown in Figures 2, 3, and 4.

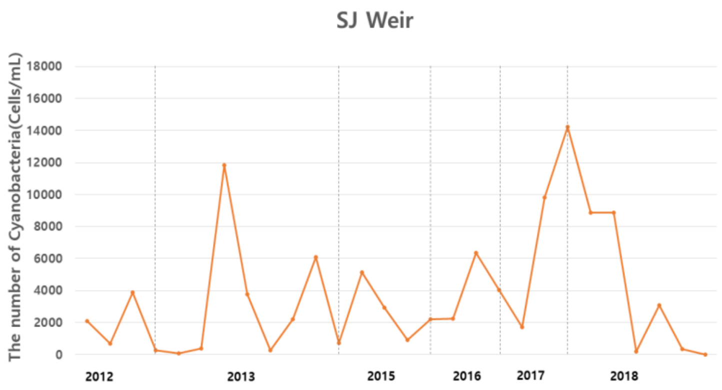

Figure 2. The number of cyanobacteria at the SJ Weir

Figure 2 shows that the SJ Weir had the number of harmful cyanobacterial cells that corresponds to the Attention level (1,000 cells/mL) or higher of the algal alarm system for five years in 2012, 2013, 2015, 2016, and 2017 during the period of seven years from 2012 to 2019. In 2013 and 2018, the figure exceeded the Alert level (10,000 cells/mL) of the algal alarm system.

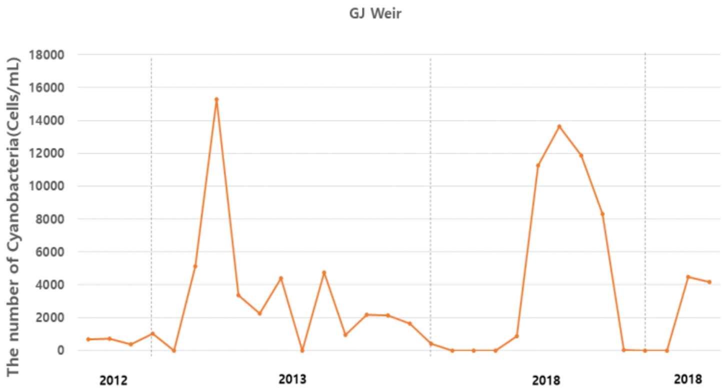

Figure 3. The number of cyanobacteria at the GJ Weir

Figure 3 shows that the GJ Weir had the number of harmful cyanobacterial cells that corresponds to the Attention level (1,000 cells/mL) or higher of the algal alarm system for four years in 2012, 2013, 2018, and 2019. In 2013 and 2018, the figure exceeded the Alert level (10,000 cells/mL) of the algal alarm system. Currently, the two weirs in the Geum River excluding the BJ Weir are completely opened in order to reduce algal bloom. For the SJ Weir, the average monthly number of harmful cyanobacterial cells is below the Alert level according to the water quality prediction standard provided by the Water Environment Information System, considering the harmful cyanobacteria population occurring recently after the weir was opened.

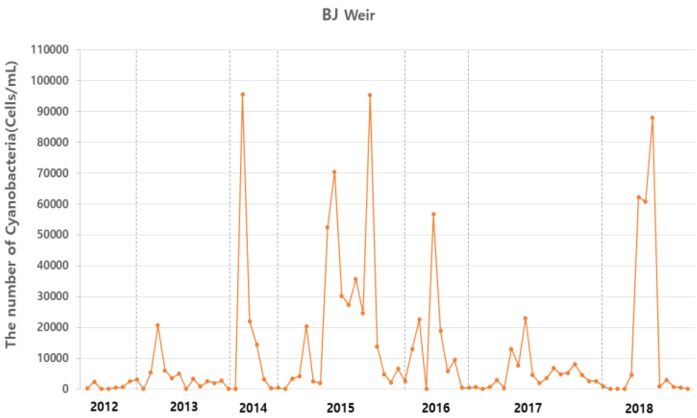

Figure 4. The number of cyanobacteria at the BJ Weir

Figure 4 shows that the BJ Weir has the highest number of harmful cyanobacterial cells every year among the three weirs. The number of harmful cyanobacterial cells corresponded to the Attention level (1,000 cells/mL) or higher of the algal alarm system for six years excluding 2019. The figure decreased in 2017 when the weir was partially opened in 2016 but increased back again in 2018. There is a significant difference in the number of harmful cyanobacterial cells among the weirs depending on time and location, which indicates that a multiple regression equation is needed for each weir in order to control the number of harmful cyanobacterial cells in the Geum River.

Table 3

Variation of water quality at each weir site from Jun 2012 to Oct 2019

		WT (°C)	pH	DO (mg/L)	TN (mg/L)	TP (mg/L)	Chl-a (mg/m^3)	NO_3-N (mg/L)	NH_3-N (mg/L)	PO_4-P (mg/L)
	Min	19.90	6.80	7.20	1.96	0.04	3.90	1.39	0.01	0.00
SJ	Mean	24.81	7.86	9.56	2.76	0.09	58.50	2.18	0.07	0.03
	Max	29.10	8.80	12.40	3.91	0.20	160.00	3.49	0.39	0.09
	Min	16.40	7.10	6.60	1.99	0.04	5.60	0.92	0.01	0.00
GJ	Mean	24.93	8.14	10.20	2.61	0.12	73.53	1.96	0.09	0.04
	Max	31.40	9.20	13.50	3.42	0.45	209.90	2.92	0.56	0.14
	Min	15.10	6.90	4.70	1.46	0.04	5.20	0.72	0.01	0.00
BJ	Mean	24.27	8.11	9.24	2.35	0.09	43.58	1.72	0.11	0.03
	Max	31.30	9.20	14.50	3.71	0.56	120.10	2.99	0.44	0.15

Table 3 summarizes the overall water quality of the Geum River in terms of various water quality parameters measured by the Water Environment Information System. The average temperature at three weir sites in the Geum River is between 24.3 and 24.9℃, which is fairly similar, indicating that the variability due to climate is insignificant among these sites. The maximum temperature increase was approximately 2℃ from downstream to upstream. The change in pH level by each site is between 7.86 - 8.14, which does not vary significantly, but it tends to increase towards the downstream. The average concentration of TN and TP at three sites are 2.35 - 2.76mg/L and 0.09 - 0.12mg/L, respectively, but these two parameters tend to increase by artificial influx of domestic sewage, industrial wastewater, and livestock wastewater. The TN value is the highest at the SJ Weir possibly due to the influx of Mihocheon tributary affecting the load of the Geum River. The average TN value tends to decrease towards the downstream. NO_3-N exhibited a similar tendency as TN. TP was the highest at the GJ Weir with the value of 0.12mg/L. It can be inferred that the value was the highest because this particular point has the greatest number of agricultural and industrial complexes (Ministry of land, 2009). PO_4-P exhibited a similar tendency as TP.

The results of correlation analysis on the number of cyanobacterial cells per water quality factor

The correlation analysis on the number of cyanobacterial cells and 17 water quality parameters was conducted based on the water quality prediction standard provided by the Water Environment Information System, water quality monitoring network data, and the data provided by the Korea Meteorological Administration. The parameters used in the correlation analysis were WT, pH level, DO, BOD, COD, SS, TN, TP, Chl-a, EC, NO3-N, NH3-N, PO4-P, DTN, DTP, and TOC. The correlation between the number of cyanobacterial cells and the water quality parameters measured at each weir was analyzed in order to find the major water quality parameters influencing on the number of cyanobacterial cells. The Pearson's correlation coefficient, which was used for analyzing the correlation between the number of cyanobacterial cells and water quality parameters for each site, is shown in Tables 4, 5, and 6 for the cases in which the average monthly harmful cyanobacteria population exceeded 1,000 cells/mL.

Table 4

Pearson Correlation coefficients between parameters about over the number of cyanobacteria's 1,000cells/mL at Sejong Weir

WT (℃)	pH	DO (mg/L)	BOD (mg/L)	COD (mg/L)	Chl-a (mg/m^3)	PO_4-P (mg/L)	DTP (mg/L)	TOC (mg/L)
.383*	.391*	.473**	.393*	.365*	.491*	-.524*	-.412*	.440**

**: p<0.01, *: p<0.05

Table 5

Pearson Correlation coefficients between parameters about over the number of cyanobacteria's 1,000cells/mL at Gongju Weir

WT (℃)	pH	BOD (mg/L)	COD (mg/L)	TN (mg/L)	Chl-a (mg/m^3)	DTN (mg/L)	TOC (mg/L)
.436*	.412*	.458*	.362*	-.380*	.458*	-.385*	.613**

**: p<0.01, *: p<0.05

Table 6

Pearson Correlation coefficients between parameters about over the number of cyanobacteria's 1,000cells/mL at Baekje Weir

WT (℃)	pH	TN (mg/L)	EC (μS/cm)	NO_3-N (mg/L)	NH_3-N (mg/L)	DTN (mg/L)
.415**	.221*	-.415*	.221*	-.371*	.222*	-.409*

**: p<0.01, *: p<0.05

Table 4 shows that nine of the 17 water quality parameters had a statistically significant correlation with the SJ Weir. Table 5 shows that eight of the 17 water quality parameters had a statistically significant correlation with the GJ Weir. Table 6 shows that seven of the 17 water quality parameters had a statistically significant correlation with the BJ Weir. The following water quality parameters exhibited a statistically significant correlation with the number of cyanobacterial cells at three weir sites: WT (0.383) ($P < 0.05$) and pH level (0.391) ($P < 0.05$) had a positive correlation at the SJ Weir, WT(0.436) ($P < 0.05$) and pH level (0.412) ($P < 0.05$) had a positive correlation at the GJ Weir, and WT (0.415) ($P < 0.01$) and pH level (0.221) ($P < 0.05$) also had a positive correlation at the BJ Weir. A previous study reported that cyanobacteria mass propagates when water temperature is 20℃ or higher (Liu et al, 2011); Roberts and Johary (1987) also reported that the maximum growth speed of cyanobacteria is reached when the temperature is 25℃ or higher. The average water temperature of each weir, which is a parameter showing a statistically significant correlation with the number of cyanobacterial cells, was 24℃, thus being similar to the findings of previous studies. The results of this study showed that water temperature and pH level have a positive correlation with the number of cyanobacterial cells, which corresponds to the findings of previous studies (Choi et al, 2013). The phosphorus concentration required for the occurrence of algal blooms is 0.02 mg/L and 0.035 mg/L according to the EPA criteria and the OECD criteria, respectively (Lee, 2013). The phosphorus concentration of the study area is 0.04 – 0.2 mg/L at the SJ Weir, 0.04 – 0.45 mg/L at the GJ Weir, and 0.04 – 0.56mg/L the BJ Weir, which all meet the condition for the occurrence of algal blooms. The average values of TP were 0.09mg/L, 0.12mg/L, and 0.09mg/L which exceed the criteria for eutrophication

Multiple regression analysis at each weir

Table 7 shows the results of a multiple regression analysis in which the number of harmful cyanobacterial cells at each weir is set as dependent variables and the water quality parameters that had a statistically significant correlation in the Pearson's correlation analysis are set as independent variables.

Table 7

The result of multiple regression analysis at each Weirs

	Independent Variable	Coefficient		Independent Variable	Coefficient		Independent Variable	Coefficient
SJ Weir	constant	-5018.668	GJ Weir	Constant	-7432.625	BJ Weir	Constant	-188058.803
	WT	621.970		WT	122.196		WT	3729.968
	pH	-1122.211		pH	605.942		pH	15037.469
	DO	517.605		BOD	39.480		TN	-36917.634
	BOD	-1862.081		COD	-271.196		EC	90.420
	COD	-115.417		Chl-a	11.152		NO_3-N	24053.159
	Chl-a	34.425		EC	1.598		NH_3-N	96211.453
	PO_4-P	-57282.962		NO_3-N	-1127.016			
	DTP	1864.331		PO_4-P	4206.244		DTN	-297.655
	TOC	542.064		DTN	571.886			
				TOC	760.414			

Dependent Variable: The number of Cyanobacteria

A multiple regression equation and correlation analysis on the number of cyanobacterial cells

Figures 5, 6, and 7 show the comparison between the number of cyanobacterial cells predicted using the multiple regression equation derived in Table 7 and the actual number of cyanobacterial cells measured. If the number of cyanobacterial cells predicted using the multiple regression equation is a negative value, it was considered that there are no harmful cyanobacteria. The correlation between the actual number of cyanobacterial cells and the number of cyanobacterial cells predicted by the multiple regression equation of each weir is shown in Figures 8, 9, and 10. Figure 8 shows that the correlation coefficient r of the SJ Weir is (0.682, $P < 0.01$), Figure 9 shows that the correlation coefficient r of the GJ Weir is (0.708, P < 0.01), and Figure 10 shows that the correlation coefficient r of the BJ Weir is (0.594, P < 0.01).

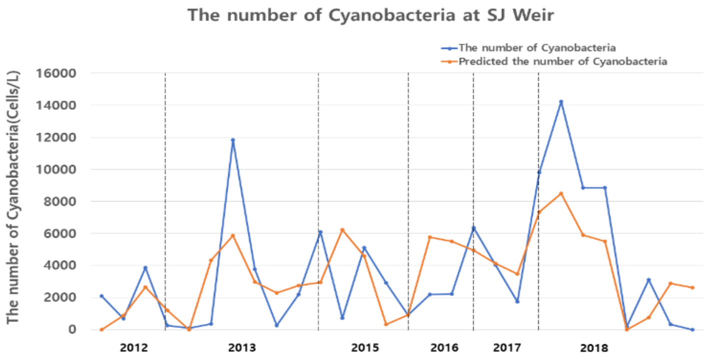

Figure 5. Actual number of cyanobacterial cells and predicted number of cyanobacterial cells at the SJ Weir

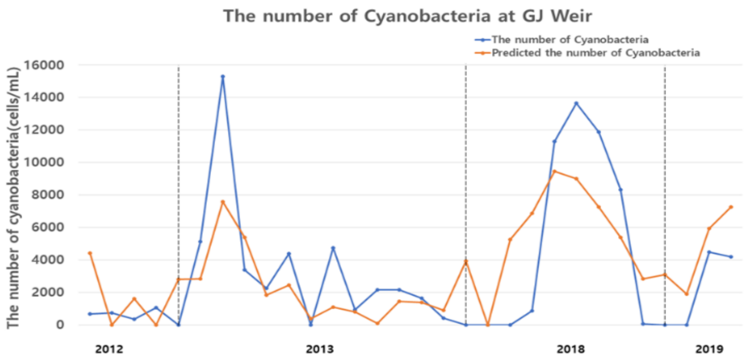

Figure 6. Actual number of cyanobacterial cells and predicted number of cyanobacterial cells at the GJ Weir

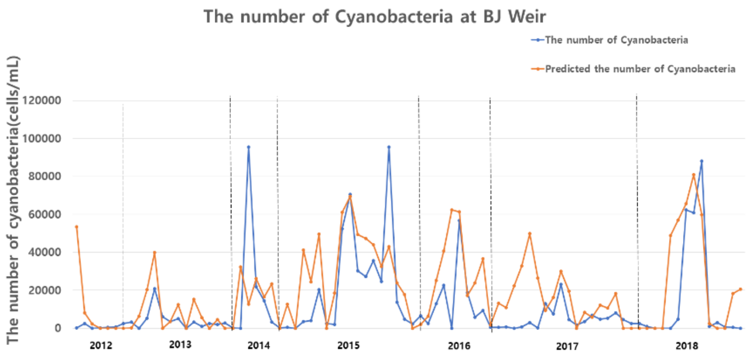

Figure 7. Actual number of cyanobacterial cells and predicted number of cyanobacterial cells at the BJ Weir

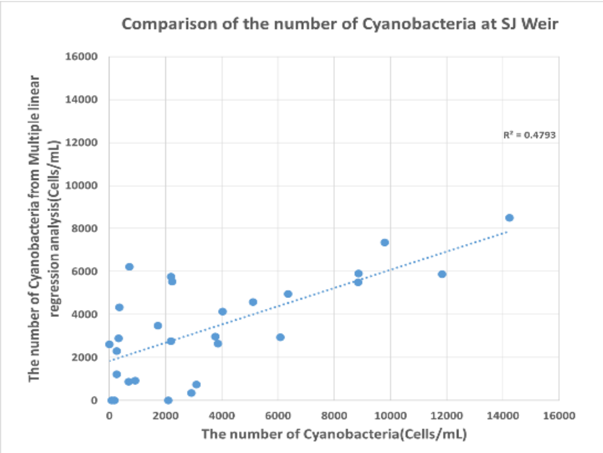

Figure 8. Comparison of the number of cyanobacteria at the SJ Weir

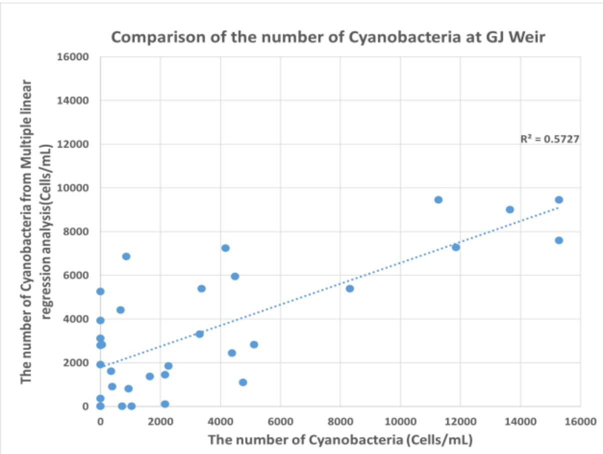

Figure 9. Comparison of the number of cyanobacteria at the GJ Weir

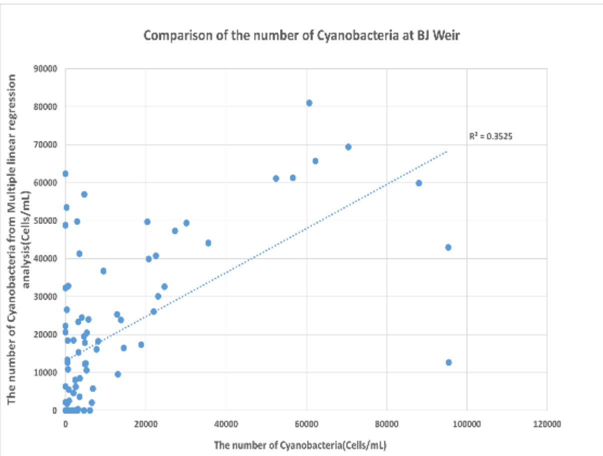

Figure 10. Comparison of the number of cyanobacteria at the BJ Weir

Conclusion

In this study, the correlation between the number of harmful cyanobacterial cells and various water quality parameters was analyzed to predict the harmful cyanobacteria population using a multiple regression equation for three weirs built in the Geum River region, and deduced the following conclusions.

First, when the correlation between the actual number of harmful cyanobacterial cells and the number of cyanobacteria cells predicted by a multiple regression analysis was analyzed, the correlation coefficient r of the SJ Weir was 0.682 ($P < 0.01$), while that of the GJ Weir and the BJ Weir was 0.708 ($P < 0.01$) and 0.594 ($P < 0.01$), respectively. The most important aspect of preventing the growth of cyanobacteria is to identify the characteristics of water quality parameters of each weir and to make accurate diagnosis. The weir that requires most improvement should be determined through this study and proper measures should be developed.

Second, the results of the multiple regression analysis of each weir showed that WT, DO, Chl-a, DTP, and TOC were found to affect the increase in the number of harmful cyanobacterial cells, while pH level , BOD, and PO4-P were found to help decrease the number of harmful cyanobacterial cells. For the GJ Weir, WT, pH level, BOD, Chl-a, EC, PO4-P, DTN, and TOC were found to affect the increase in the number of harmful cyanobacterial cells, while COD and NO3-N were found to help decrease the number of harmful cyanobacterial cells. For the BJ Weir, WT, pH level , EC, NO3-N, NH3-N were found to affect the increase in the number of harmful cyanobacterial cells, while TN and DTN were found to help decrease the number of harmful cyanobacterial cells.

Third, the correlation analysis between the number of cyanobacterial cells and water quality parameters showed that among 17 parameters including precipitation amount, WT, pH level, DO, BOD, COD, SS, TN, TP, Chl-a, EC, NO3-N, NH3-N, PO4-P, DTN, DTP, and TOC, the parameters that had a statistically significant correlation with the number of harmful cyanobacterial cells at the SJ Weir were WT, pH level, DO, BOD, COD, Chl-a, PO4-P, and TOC. At the GJ Weir, the parameters that had a statistically significant correlation with the number of harmful cyanobacterial cells were WT, pH level, BOD, COD, TN, Chl-a, DTN, and TOC; at the BJ Weir, the parameters that had a statistically significant correlation with the number of harmful cyanobacterial cells were WT, pH, TN, EC, NO3-N, NH3-N, and DTN. Appropriate management and response measures are needed since the parameters that are correlated with harmful cyanobacteria vary by weir.

This study has a significance in that it provides basic data for establishing water quality management policy for weirs in the downstream of the Geum River. Further studies are needed on nutritive salts and sediments that are influenced by WT and pH level, and the multiple regression equation of the number of cyanobacterial cells proposed in this study can be used to predict the possible cyanobacteria population depending on the concentration of water quality parameters, thus being utilized in water quality management of the Geum River.

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